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Chapter 14

DAMAGE TO MILITARY FIELD EQUIPMENT [redacted]

[redacted] INTRODUCTION [redacted]

[redacted] One of the primary uses of nuclear weapons would be for the destruction of military field equipment. This chapter describes how a nuclear explosion can damage military field equipment and provides techniques for estimating certain types and categories of damage. Section I provides a description of the mechanisms of air blast damage to military field equipment, and some examples of variations in damage with weapon yield and exposure conditions. Section II provides the techniques for estimating the various categories of air blast damage to military material. Section III provides a brief description of damage that might be caused by missile (objects translated by the blast wave), fire, and other secondary effects. Section IV discusses transient radiation effects on electronic systems (TREES).

SECTION I

[redacted] AIR BLAST DAMAGE [redacted]

[redacted] The military equipment that is included in this section generally can be described as that material that is used by ground forces in the field. The major types include vehicles (wheeled and tracked), artillery, small arms, communications, field radars, mines, railroad rolling stock, generators, and other miscellaneous items. Types of equipment that are specifically excluded are stationary structures, aircraft, and missile systems. The blast and thermal effects on these three types are discussed in Chapters 11, 13, and 16, respectively. This section discusses the causes and categories of blast-induced damage to the types of equipment listed above, while techniques for predicting the damage are given in Section II.

14-1 Damage Mechanisms [redacted]

[redacted] Most damage to military equipment is caused by the deforming action of blast overpressure or by target movement associated with the air in motion within a blast wave, i.e., the dynamic pressure. The sudden application of high pressure to the surface of a target as a blast wave envelops it can cause crushing, distortion, or buckling of components and subsystems. These may be either closed components and subsystems whose strengths are less than the forces imposed by the differential pressure between the outside and the inside of the element (e.g., fuel tanks), or open elements on which differential forces occurring during the time taken for the blast wave to envelop the element are large enough to cause failure. This type of damage predominates for very low yield weapons or for short duration pulses.

[redacted] If the weapon yield is greater than several hundred tons, however, the predominant type of damage to targets in the open results from the drag force caused by dynamic pressures. These drag forces may be large enough to move properly oriented, unshielded targets great distances. They may slide, roll, or bounce along the ground surface and may be damaged seriously by the violent motions. There have been instances in which heavy equipment has been picked up and thrown dozens of feet, and then has hit the ground with sufficient force to be dismembered. Stresses induced by dynamic pressure on other types of equipment, e.g., radar or

[redacted]

[redacted] radio antennas, can be large enough to cause failure even though the target is not crushed and no gross movement occurs prior to failure.

[redacted] The preceding discussion shows that the three most important parameters involved in damage to equipment from air blast are the air blast environment, the characteristics of the target, i.e., those factors that influence its reactions to blast loadings, and the target exposure, i.e., those factors, principally target orientation and shielding, that influence the target loading and the reaction of a target to a particular blast loading.

14-2 Air Blast Environment [redacted]

[redacted] The various means by which air blast can damage a target can be developed most simply by considering the idealized case in which a classical, sharp fronted blast wave moving over the ground encounters a rigid, fixed cube, as previously described in Section II of Chapter 9. If the height of burst (HOB) and ground distance are scaled as the cube root of the yield, the overpressure Δp remains constant, but the shock wave duration t^+ (as in Chapter 9, the positive phase overpressure duration t_p^+ and the positive phase dynamic pressure duration t_q^+ are assumed to be equal and are designated t^+) varies as the cube root of the yield. Thus, as shown in Chapter 9, the total impulse is represented by

$$I_T = A\left[B + C\,(W^{1/3})\right],$$

where A is the area of the face of the cube normal to the blast wave, B is the overpressure contribution to the impulse, and C is the dynamic pressure contribution to the impulse. Thus, the contribution to total impulse from overpressure remains constant, while that from dynamic pressure increases as the cube root of the yield. For very low fractional kiloton yields, the loading is highly impulsive with most of the load coming from the overpressure contribution. As the yield increases, at a constant scaled HOB and ground distance, the total impulse also increases, with an increasing portion resulting from the dynamic pressure contribution.

[redacted] To maintain the *same* loading on a target as the yield increases (with a constant $W^{1/3}$ scaled HOB), the actual ground distance must increase at a faster rate than would be necessary to maintain peak overpressure constant, that is, faster than the cube root of the yield. In other words, if HOB is scaled as $W^{1/3}$, ground distance must be scaled as W^n, where $n > 1/3$, to maintain the same loading on the target.

[redacted] This fact has been demonstrated by theoretical calculations of the relationships between yield and ground distance for a particular target, and a particular total impulse. Typical of such calculations is that performed for the blast wave from surface burst incident on a 20 foot fixed cube at distances such that the total impulse would be 0.5 psi-sec. The results of the calculation are shown in Figure 14-1.

[redacted] An excellent fit to the curve shown in Figure 14-1 was achieved with an equation of the form

$$\text{Ground Distance} = (\text{constant})(\text{yield})^n,$$

where $n = 0.4138$.

[redacted] For many years, it has been observed that experimental data concerning damage to military equipment required ground distance scaling of about $W^{0.4}$. The closeness of this exponent to that derived above suggests strongly that the reason for the observed scaling is that the damage was related closely to total impulse. This hypothesis was confirmed by curve-fitting analyses of the relationships between damage to various types of equipment and various air blast parameters. Typical of the results of these analyses is one for damage to 1/4-ton trucks whose sides were exposed to blast waves from weapons ranging in yield from 0.01 kt to 10 Mt. Damage

[redacted]

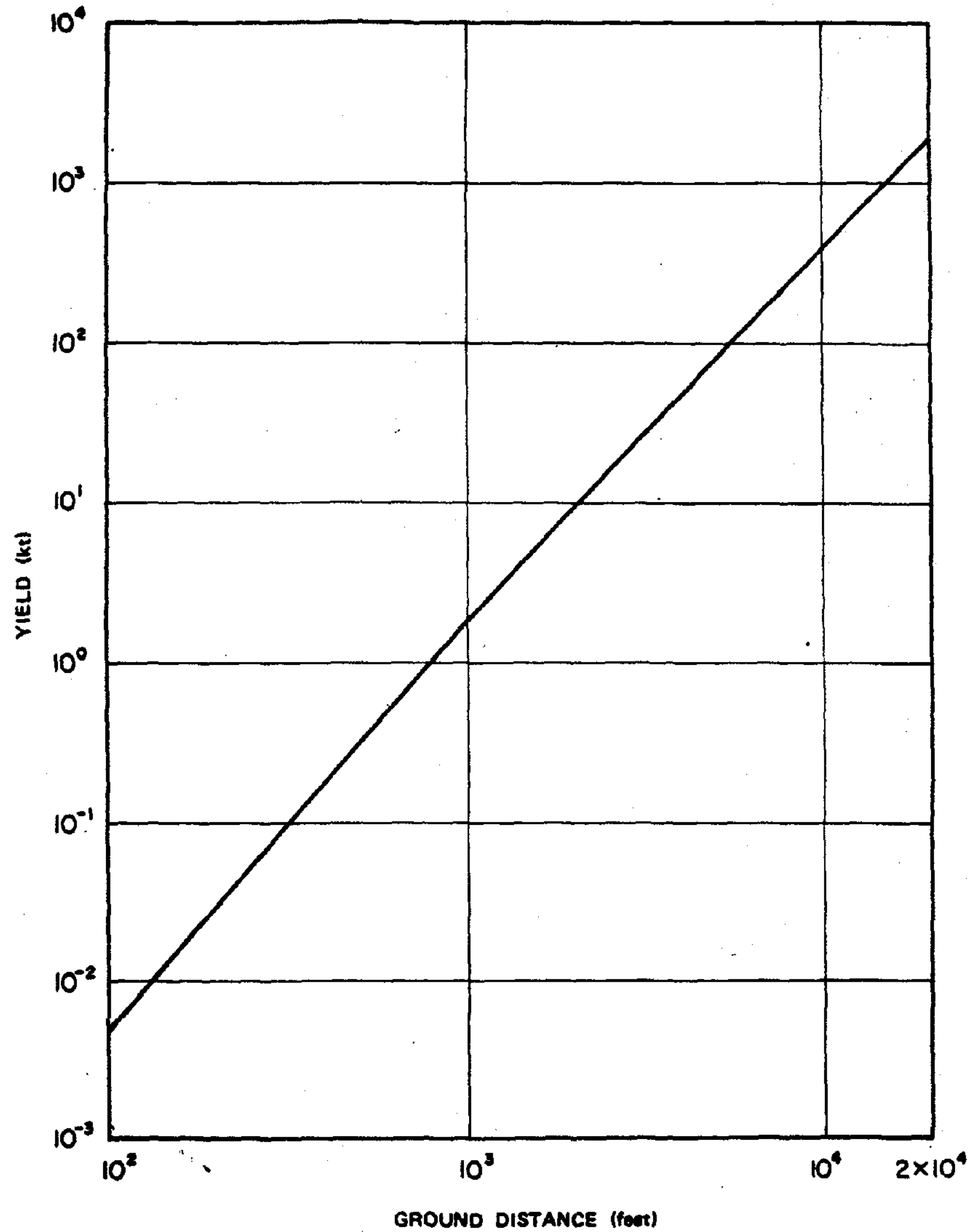

Figure 14-1. [redacted] Surface Burst Ground Range as a Function of Yield for Constant Total Impulse of 0.50 psi-sec [redacted]

[redacted]

[redacted] correlation was best with total impulse (with an index of determination, I.D., of 0.77),* but the correlation was almost as good with dynamic pressure impulse (I.D. = 0.74). Much poorer correlation was achieved with dynamic pressure, diffraction impulse, and overpressure (with I.D.'s of 0.26, 0.24 and 0.22 respectively).

[redacted] Most of the foregoing discussion is concerned with air blast phenomena in the Mach reflection region, where the majority of targets usually are found. In the regular reflection region, the overpressure portion of the total impulse usually dominates. This is because the target is exposed to both the incident and reflected air shock, and the horizontal components of dynamic pressure for the two shocks are small, largely because the horizontal component of dynamic pressure is proportional to the square of the sine of the angle θ that the shock front makes with the surface. For example, if θ is 45-deg, the horizontal component of dynamic pressure would be about one-half as much as the dynamic pressure for a shock making an angle of 90-deg with the surface (which is essentially the case in the Mach region). For 30-deg, the horizontal component would be only about one-fourth as much.

[redacted] In this review of the discussion of the response of a simple cube to air blast a classical, sharp fronted shock wave was assumed to be incident on the cube. The influence of disturbed or non-classical wave shapes on the impulse delivered to a target can be extensive. If the wave form is not sharp-fronted, a considerable rise time may occur before the peak pressure is observed (see the wave shapes in Figures 2-40 and 2-41 of Chapter 2). If the peak overpressure is not at the front of the wave, the relationships between reflected pressure, shock velocity, sound speed, and overpressure are not valid. Furthermore, such nonideal shock waves usually are associated with precursors, within which peak dynamic pressure is not related to peak overpressure as it is with sharp fronted waves, and the dynamic pressure impulse contribution to total impulse given in Section II of Chapter 9 for a simple cube is not valid. Damage still can be related to observed air blast parameters (observed overpressures and dynamic pressures) for such wave shapes, but these parameters are not interrelated as they are for ideal waves.

14-3 Target Characteristics [redacted]

[redacted] Two types of target characteristics generally are of importance: the overall geometry of the target, on which blast loadings depend; and the distribution of mass in the target, which determines the kind of motions induced by the blast loading. (These can be interrelated in cases when the response of a target during loading changes its geometry and therefore its loading.)

[redacted] The influence of geometry can be illustrated by considering two targets with the same cross-sectional area, one of which is composed of flat surfaces and sharp edges while the other has curved surfaces and a more streamlined shape. The target with flat surfaces and sharp edges will have a higher load because its shape will result in higher reflected pressures and drag coefficients than will occur on the smoother target. Consequently, the level of air blast required to induce motion in the non-streamlined target will be less than for the streamlined target.

[redacted] The influence of mass distribution in a target can be seen by noting that for two targets of the same shape, mass, and area, but with different centers of gravity, the one with the higher center of gravity is more likely to sustain damaging motions than the one with the lower center of gravity. Furthermore, a target with a low mass will undergo greater motions than one with a high mass, if the two have the same area, shape, and location of the center of gravity. Figure 14-2 illustrates some of the types of blast-induced motion that may occur, depending

*[redacted] The index of determination (ID) is used as a measure of goodness of fit of a curve. The closer the ID is to the number one, the better the fit of the curve.

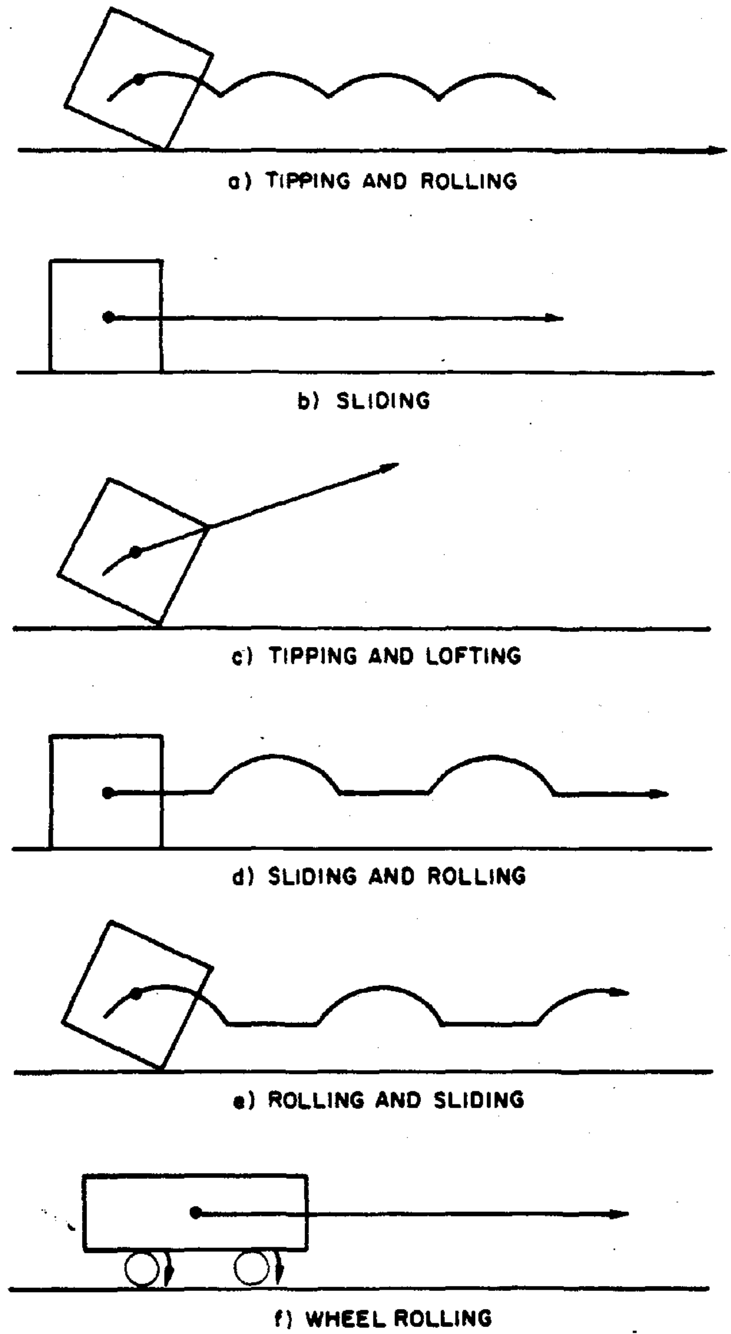

Figure 14-2. [redacted] Target Response Modes [redacted]

[redacted] upon geometry and mass distribution.

[redacted] A detailed assessment of the influences of [redacted]metry and mass distribution for each piece of equipment is not presented in this chapter. The damage assessment techniques that are presented in Section II for a variety of equipment types (e.g., wheeled vehicles, artillery pieces, tanks) and for a number of items of equipment within each type, are all based on experimental observations. One purpose of this paragraph is to emphasize the fact that different items of equipment within a single type, and even different production runs of the same item of equipment, can exhibit significant differences in damage from the same blast loadings, but they also can exhibit similarities. These differences and similarities are illustrated by several curves that show damage as a function of distance in a manner similar to Figure 14-3, in which damage on an increasing scale from none to severe is the vertical coordinate (the meanings of the damage categories shown in Figure 14-3 are described in Section II), and distance from a 1 kt surface burst at which the various categories of damage have been observed is the horizontal coordinate.* Increasing distance implies decreasing values of blast parameters, so the curve indicates that damage decreases with an increase in distance from the burst point. There are infrequent exceptions to this rule, which generally occur in the regular reflection region for large heights of burst.

[redacted] Figure 14-4 shows a comparison of the da[redacted]ge-distance curves for two types of wheeled vehicles. Although the two vehicles differ markedly in their characteristics, the ground distances at which they sustain moderate and severe damage are not very different; however, the difference in the distances for light damage is large. Figure 14-5 shows larger differences in the damage-distance curves for the similar artillery pieces. Finally, Figure 14-6 shows fairly substantial differences in the distances at which severe and light damage occurs for two different production runs of the same vehicle.

[redacted] These comparisons illustrate the difficu[redacted] that can be expected to be encountered in making damage predictions for new items of equipment for which little or no information is available.

14-4 Target Exposure [redacted]

[redacted] The orientation of the target with respect [redacted]o the direction of travel of the blast wave, and shielding afforded by nearby terrain features can affect the response of the target significantly. The effects that differences in target exposure can have on damage may be illustrated by curves similar to the schematic presentation in Figure 14-3.

[redacted] The terminology that is usually used when discussing target orientation describes which side faces the oncoming blast wave, i.e., side-on,† front-on, or rear-on to the blast. A flat surface oriented obliquely or normal to the blast will receive substantially different loads than it would if it were parallel to the blast wave. Little difference in damage is observed for front-on and rear-on orientations for many targets; in this chapter the two orientations are grouped into a single category, end-on orientation. Figure 14-7 illustrates the importance of target orientation to the extent of damage.

[redacted] A target may be shielded from some of the air blast and thermal radiation effects when some substantial object or terrain feature (natural or man-made) is in the vicinity of the

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*[redacted] Curves were drawn by finding the horizontal scaled dista[redacted]s (d1, d2, etc.) at which changeover from each category of damage to the next higher category occurred. The points so derived were connected by smooth curves.

†[redacted] The term "side-on" is also used in an alternate designation fo[redacted]ncident pressure in a blast wave, i.e., "side-on overpressure" is the overpressure in an incident blast wave before it interacts with a target or object.

[redacted]

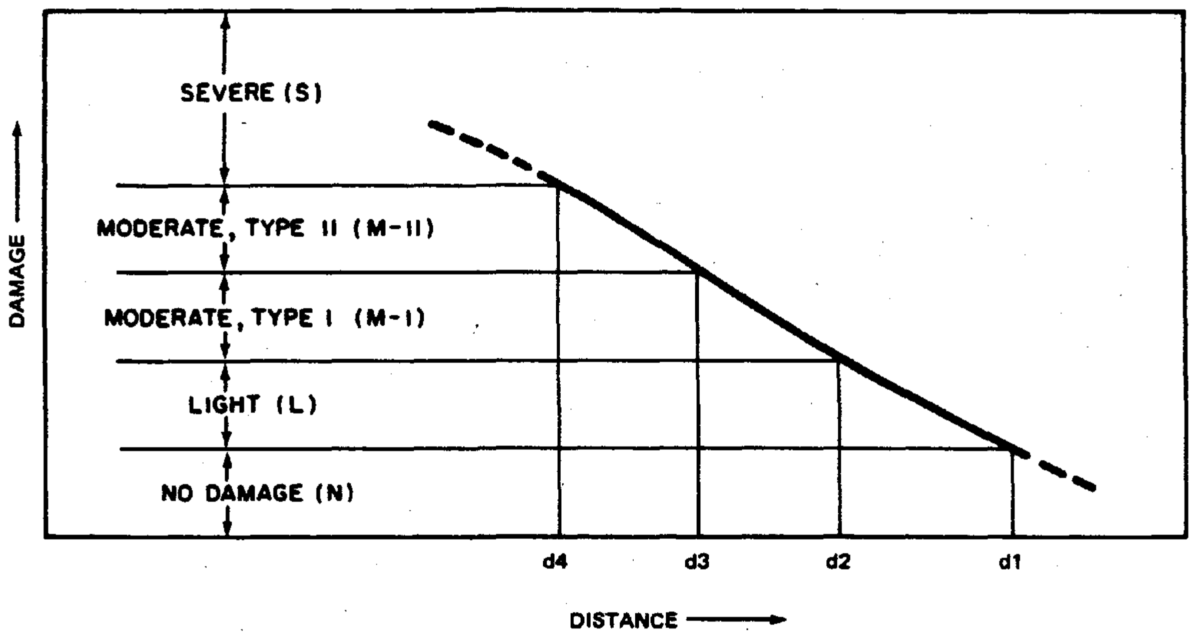

Figure 14-3. [redacted] Illustration of the Damage vs Distance Curve [redacted]

Figures 14-5 through 14-7
(Pages 14-8 through 14-11)
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[redacted]

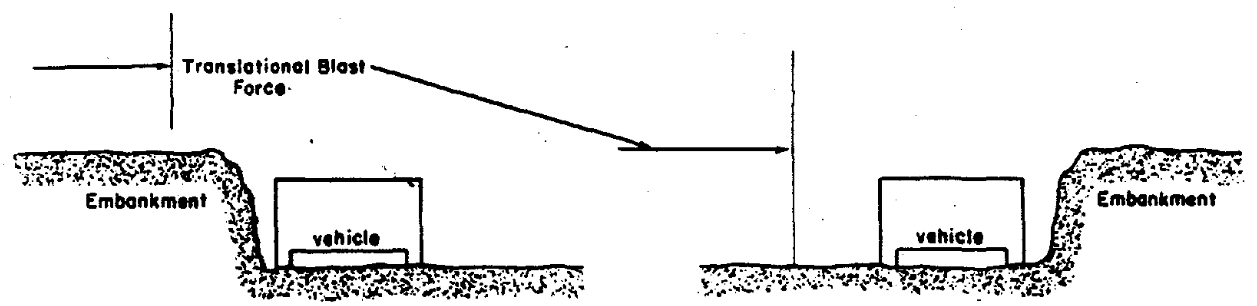
[redacted] target. Shielding is most effective when the obstacle is between the target and ground zero.

[redacted] Obstacles that are considered in the assessment of the effects of shielding from air blast are local obstacles, such as ravines, constructed slots, or revetments (the effects of large terrain features on blast waves are discussed in paragraphs 2-38 through 2-41 of Chapter 2). The importance of shielding is well documented. Comparisons of damage between shielded and unshielded vehicles exposed to blast from both nuclear and chemical explosions are available. The effectiveness of an obstacle in shielding a target generally results as much from its capability to reduce the target movement as from its ability to modify the blast environment. Figure 14-8 illustrates this point. When the obstacle is between the blast wave and the target most of the impulse or translational force that induces motion (drag loading) does not act on the target. When the obstacle is "behind" the target, the translational force initially applied to the target is the same as it would have been without an obstacle, but the obstacle not only can modify later translational forces (as a result of shock wave reflection), but it can restrict movement, the major cause of damage. The overpressure effects of crushing and fracturing still occur in both cases, and these effects provide lower limits for damage ground distances.

[redacted] Most damage resulting from low yield weapons is caused by overpressure impulse rather than translation, even for unshielded targets, and, since overpressure impulse is not altered drastically by shielding, the effects of shielding are relatively minor for such weapons. However, most damage caused to non-shielded targets by higher yield weapons results from the translational effects of dynamic pressure. Since shielding can reduce translational effects substantially, it can be quite effective as a protection from large yield weapons. Damage to shielded targets results largely from overpressure effects, for which damage distances scale as the cube root of the yield ($W^{1/3}$), while damage to unshielded targets results largely from total impulse effects (including those of dynamic pressure), for which damage distances generally scale as $W^{0.4}$. The effects of shielding are illustrated in Figure 14-9, in which damage distances for shielded targets have been scaled as $W^{1/3}$, and those for unshielded targets by $W^{0.4}$.

14-5 Effects of Ground Surface Conditions [redacted]

[redacted] Ground surface conditions affect damage in two ways: by modification of the blast parameters; and by modification of target response. The former is discussed in paragraphs 2-20 through 2-22 and 2-37 through 2-41 of



(a) No translation because Translational Force is not applied

(b) No or little translation because embankment restricts movement

Figure 14-8. [redacted] The Effect of Shielding [redacted]

Fig 14-9 Page 14-13 Deleted. USANCA (b)(1)

[redacted] Chapter 2. The latter is discussed here. Information on the effects of ground condition comes from available test data on vehicles exposed on test surfaces constructed to investigate precursor phenomena. These surfaces were desert, asphalt, and desert covered with water. An analysis of these data concluded that there was a significant difference in damage to vehicles on "hard" (non-yielding, non-deforming) and "soft" (yielding, deforming) surfaces. This is illustrated by the curves in Figure 14-10. Blast wave characteristics were different at comparable scaled distances over the two surfaces. Therefore, a scale showing comparable blast wave conditions, dynamic pressure impulse, was substituted for the distance scale shown in previous figures in order to remove the influence of surface conditions on the blast wave from the comparison.

[redacted] Figure 14-10 shows that surface conditions can influence damage substantially, particularly in the moderate-to-severe categories. This is believed to result from the difference in the target response caused by the difference between the two surfaces shown in Figure 14-10. A soft surface will yield and can be deformed. These surface reactions produce resistive forces against the wheels, which tend to cause the vehicle to tip over. The same vehicle would tend to slide on a hard surface and would not necessarily overturn. The response of a vehicle on a soft surface is likely to resemble the response modes illustrated in Figure 14-2a, c, or e, whereas the same vehicle exposed on a hard surface would be more likely to exhibit the response modes illustrated in Figure 14-2b and d.

[redacted] Data, such as shown in Figure 14-10, are insufficient to incorporate the effects of surface conditions in the damage prediction techniques given in Section II, except as a source of error that degrades the reliability.

14-6 Vehicle Status [redacted]

[redacted] The response of a vehicle to the air blast wave can be influenced by whether or not the brakes are on and/or the transmission is in gear at the time of exposure. Information concerning these influences is available [redacted] Differences in the resulting damage occur primarily for end-on orientation of vehicles. Figure 14-11 illustrates the differences between the damage categories for two comparable [redacted] vehicles. A similar comparison for side-on orientation showed very good agreement, thus the difference shown in Figure 14-11 can be attributed chiefly to differences in vehicle status and not to difference of configuration between [redacted] 1/4-ton trucks.

Data (b)(1)

[redacted] When a vehicle is exposed end-on with the brakes off and the transmission out of gear, the primary response is rolling on its wheels rather than sliding or overturning. As shown in Figure 14-11, there appears to be an upper limit on the blast forcing function, above which the vehicle will overturn because the forces are too great to be absorbed by rolling or sliding, or because the probability of encountering an obstacle to substantial movement is high. The status of the vehicle at the time of exposure may be as significant in determining the resulting damage as the orientation or even shielding; however, there are insufficient data to include this factor in the damage prediction techniques with any degree of confidence.

Fig 14-10 + 14-11 on pages 14-15 + 14-16 Deleted. USANCA (b)(1)

SECTION II

[redacted] DAMAGE PREDICTIONS [redacted]

14-7 Definitions of Damage Categories [redacted]

[redacted] The causes of damage to military field equipment by the air blast wave were described in Section I. The description of the various levels of damage (ranging from none to total) must be defined before damage predictions can be made. Various descriptors have been employed over the years by informed and experienced appraisers of damage to describe what they considered to be the degradation of the military effectiveness of various items of equipment. These descriptors, while useful, tend to be somewhat subjective, and they could result in different appraisals of the importance of damage to various items of equipment by different people.

[redacted] An attempt has been made throughout this manual to describe the damage categories in sufficient detail to indicate the specific damage that applies to a given descriptor (e.g., Tables 11-1 and 11-2, Chapter 11, and Table 12-1, Chapter 12). In this chapter, an attempt has also been made to make the definitions of the damage descriptors less subjective in terms of the availability of a target to perform its intended military functions than descriptor definitions that have been used previously. The definitions that will be presented below include descriptions of the type and level of effort that would be required to restore a target to a condition in which it could perform its intended function, i.e., the definitions provide some insight into the time that would be required to perform essential repairs, although they do not include a measure of any effects that might arise as a result of a time lag before repair (see paragraph 14-13).

[redacted] To arrive at less subjective definitions, the various items of equipment, which have been examined subsequent to exposure to nuclear and H.E. tests, were divided into functional subsystems. This was done for two reasons: (1) more precise descriptions of damage could be obtained by considering subsystems than could be obtained by considering the item as a whole; (2) different subsystems can have different degrees of impact on the ability of a particular item of equipment to perform its basic function. Four damage levels were defined for each subsystem: no damage; damaged, but functional; damaged, nonfunctional, but repairable; damaged, nonfunctional, and not repairable.

[redacted] Damage categories for the entire piece of equipment were then defined *in terms of damage sustained by the subsystem.* The damage categories that were adopted are defined in Table 14-1.

[redacted] The subsystems that were identified for wheeled vehicles are shown in Table 14-2 to illustrate the type of system divisions that were employed.

[redacted] Of the subsystems listed in Table 14-2, the engine, power train, wheels, and chassis were designated critical subsystems which, if they sustain any damage – even easily repairable damage – so as to render them nonfunctional, would render the entire piece of equipment nonfunctional. Operator appliances and parts of the body generally can sustain some degree of damage that might make the individual element nonfunctional (a windshield may be broken, for example, or the hood could be torn off) but would not prevent the vehicle from performing its basic function.

[redacted] Although the system for identifying damage categories described above reduces the chances of differences in making damage appraisals, some subjectivity is unavoidable, especially in the determination of whether an element of a subsystem can be repaired. A bent steering column, for example, (part of a noncritical subsystem – operator appliances) is deemed to be non-repairable, i.e., normal prac-

Table 14-1. [redacted] Definitions of Damage Categories [redacted]

Damage Category	Explanation
Light	Damaged, functional (no critical subsystems – and less than half of all subsystems – are nonfunctional)
Moderate Type I	Damaged, nonfunctional, repairable with little or no special tools, parts or skills (at least one *critical* subsystem is nonfunctional, but repairable)
Moderate Type II	Damaged, nonfunctional, repairable with special tools, skills, and parts (at least half of all subsystems are nonfunctional but repairable)
Severe	Damaged, nonfunctional, very difficult to repair (at least one subsystem is nonfunctional and not repairable)*

*[redacted] An exception to this rule could occur if an otherwise not repairable subsystem could be made functional by replacing it with an immediately available spare.

[redacted] tice would be to replace it although with difficulty, and with appropriate tools, it could be repaired.

[redacted] Some typical descriptions of damage to various subsystems of a variety of items of equipment that have been assigned to the four damage categories are shown in Table 14-3. For obvious reasons this table is by no means complete (many equipment items have five or more subsystems). It is included to make the meanings of the damage categories clearer.

14-8 Prediction Techniques [redacted]

[redacted] Two types of prediction techniques are presented in this section. For individual pieces of equipment, tables are used to relate (directly or indirectly) the damage categories described in the previous paragraphs to the air blast parameter that results in a particular level of damage.

[redacted] To determine ground distance for a particular level of damage, the tables are consulted first, then air blast height of burst curves in Chapter 2 are used to find the scaled (1 kt) ground distance associated with the particular air blast parameter. Finally, appropriate scaling

Table 14-2. [redacted] Wheeled Vehicle Subsystems [redacted]

Subsystem	Name and Description
A	Operator Appliances – such as instruments, driving controls, windshield
B	Body – sheet metal work such as fenders, hood, etc.
C	Engine – including fuel, electrical, and cooling systems
D	Power Train – transmission, drive shaft, axles
E	Wheels – tires, suspension, brakes
F	Chassis – basic frame of vehicle

[redacted]

Table 14-3. [redacted] Typical Subsystem Damage for Various Damage Categories [redacted]

Type of Equipment	Damage Category							
	Light		Moderate Type I		Moderate Type II		Severe	
	Subsystem	Damage Description	Subsystem	Damage Description	Subsystem	Damage Description	Subsystem	Damage Description
Wheeled vehicles	Body	Glass breakage, bent fenders.	Engine	Air cleaner blown off.	Power train	Transmission broken.	Chassis	Gross frame distortion.
Artillery	Sighting	Glass breakage in optics.	Aiming	Traversing mechanism jammed.	Tube	Recoil mechanism inoperable.	Aiming	Elevating mechanism destroyed.
Tanks	External fittings Gun tube	Bent fenders. Some dirt in tube.	Aiming	Elevating mechanism jammed.	Tracks	Idlers broken, tracks bent and twisted.	Hull	Turret torn off.
Small arms	Stock/Grip	Cracked stock.			Stock/Grip	Broken stock.	Receiver/-barrel	Dismembered.
Supply dumps*	Packaging	Packaging not ruptured, items may be scattered.					Packaging	Packaging ruptured.

*POL in 5 and 55 gal. drums; ammunition and rations in standard packages; other items in small containers.

[redacted]

factors are applied to the scaled ground distance to find the actual ground distance. For broader classes of equipment, "Damage-HOB" curves are presented. These are curves that give scaled distances for particular damage categories as a function of scaled height of burst.

[redacted] The first technique, though it incorporates one additional step to find damage ranges, provides the user with some knowledge of the air blast parameters that cause damage and, by inference for certain pieces of equipment, some insight into how the equipment is damaged. For shielded equipment, for example, where, as has been discussed, the principle agents of damage are overpressure effects, the tables show this dependence as well as the need for $W^{1/3}$ scaling. Similarly, some items of equipment (antenna masts, wire entanglements subjected to bursts from medium or large weapons) are particularly susceptible to wind loading (dynamic pressure) damage, with little or no damage due to overpressure effects. Again the tables show this as well as the required $W^{1/3}$ scaling which is appropriate for dynamic pressures.

[redacted] The largest variety of equipment should be sensitive (for reasons given in Section I) to total impulse delivered to the target. Unfortunately, actual total impulse is very difficult to determine. The overpressures portion of total impulse is sensitive to the particular geometry of

[redacted]

[redacted] the item of equipment being examined. It was demonstrated in paragraph 14-2 that, at least for 1/4-ton trucks oriented side-on to the blast, dynamic pressure impulse ranked second only to total impulse as an air blast parameter to which damage could be related. Thus, with a relatively small loss in accuracy (which would be largest for low yield weapons, for which overpressure effects tend to dominate), dynamic pressure impulse could be employed as an air blast parameter to correlate damage levels.

[redacted] Unfortunately, height of burst curves are not readily available for dynamic pressure impulse (which would be employed in the second step in the analysis). Therefore, the tables give values of "equivalent overpressure" (Δp_{eq}) or "equivalent dynamic pressure" (q_{eq}), defined as that overpressure under near-ideal conditions, or that dynamic pressure under nonideal conditions (see paragraph 2-20 for a discussion of near-ideal and nonideal surfaces) for a particular yield and height of burst at which the dynamic pressure impulse that would cause a particular level of damage ~~would be experienced. Where~~ Δp_{eq} or q_{eq} are listed ~~as damage causing parameters~~, ground distance scaling of $W^{0.4}$ should be used.

[redacted] The damage prediction technique for individual items of equipment uses three tables and a single graph. Table 14-4 lists the equipment and identifies the appropriate table (14-5, 14-6, or 14-7) from which damage information may be obtained. Table 14-5 is for equipment that is damaged principally by total impulse (as measured by Δp_{eq} or q_{eq}), with which $W^{0.4}$ scaling should be used; Table 14-6 is for equipment that is sensitive to overpressure (Δp), with which $W^{1/3}$ scaling should be used; and Table 14-7 is for equipment that is sensitive to dynamic pressure (q), with which $W^{1/3}$ scaling should be used. Tables 14-5 and 14-6 are for use in the Mach shock region only. Table 14-7 can be used in both the Mach and regular reflection region (see paragraph 2-18 for a discussion of Mach and regular reflection regions).

[redacted] The graph used in the prediction technique, Figure 14-12, relates peak dynamic pressure q to peak overpressure Δp for sharp fronted shock waves. It is useful for determining ground distances for damage to equipment that is sensitive to either equivalent dynamic pressure (q_{eq}) or actual dynamic pressure (q) for values of q below those shown in the dynamic pressure height of burst curves in Chapter 2 (distances beyond about 1,200 to 1,400 feet for a 1 kt burst). Beyond these distances, the shock waves generally are of classical form, and dynamic pressure at the wave front can be related to peak overpressure (see paragraph 2-17). The peak overpressure height of burst curves of Chapter 2 extend to about 12,000 ft from a 1 kt surface burst, and to about 25,000 feet for a 1 kt air burst (where overpressure is as low as 0.25 psi and dynamic pressure as low as 0.0015 psi).

[redacted] Tables 14-5 through 14-7 generally show the value of the air blast parameter at which there is a 50 percent probability that the item of equipment will experience the indicated damage or greater. In those cases where sufficient information is available to determine the effect of orientation, values are shown for side-on (SO), end-on (EO), and random orientation. If sufficient information is not available, values are only shown for random orientation.

[redacted] Figures 14-13 through 14-27 show iso-damage – height of burst curves for broad classes of equipment as listed below:

Figure	Equipment
14–13	Wheeled Vehicles,
14–14	Artillery,
14–15	Tracked Vehicles (Except Tanks and Engineer Heavy Equipment),
14–16	Tanks (Light and Heavy),
14–17	Small Arms,

[redacted]

14–18 Generators,
14–19 Locomotives,
14–20 Box Cars,
14–21 Supply Dumps,
14–22 Telephone Poles,
14–23 Water Storage Equipment,
14–24 Shielded Wheeled Vehicles,
14–25 Shielded Engineer Heavy Equipment,
14–26 Signal, Electronic Fire Control Equipment, Antennas, and Rigid Radomes
14–27 Wire Entanglements.

A discussion of damage to untested equipment that is not included in Tables 14-5 through 14-7 or in Figures 14-13 through 14-27 is provided in paragraph 14-9 together with estimates of some damage levels.

[redacted] Scaling procedures for use with Figures 14-13 through 14-27 are described in Problems 14-4 and 14-5 as well as on each figure. Strictly speaking, the damage-distance relationship does not scale as a simple power of yield for the classes of equipment included in this family of figures. The yield dependence of the scaling should be reflected by the curves in a manner similar to the presentations of damage to structures in Figures 11-2 through 11-23. Such a family of curves is in preparation; however, they are not available for inclusion in this manual. It is anticipated that such curves will be incorporated in a future change.

Table 14-4. [redacted] List of Equipment and Corresponding Prediction Tables [redacted]

Equipment Item	Air Blast Parameter: Near-Ideal	Air Blast Parameter: Nonideal	Table
	Unshielded Equipment		
Wheeled Vehicles			
U.S. WW II 1/4-ton truck	Δp_{eq}	q_{eq}	14-5
U.S. M-38 1/4-ton truck	"	"	"
U.S. 2-1/2-ton truck	"	"	"
U.K. scout car	"	"	"
U.K. 1/4-ton truck	"	"	"
Artillery			
Towed U.S. 57-mm anti-tank gun	"	"	"
Towed U.K. 25-pounder gun	"	"	"
Self-propelled guns	q	q	14-7
Landing Vehicle, Tracked	Δp_{eq}	q_{eq}	14-5
Armored Personnel Carrier, M-59	"	"	"
Construction Equipment			
Crawler tractor	"	"	"
Road grader	"	"	"
Tanks	Δp_{eq}	q_{eq}	14-5
Generators	"	"	"
Railroad Cars	"	"	"
Radio Sets	"	"	"
Radio Aerials			
Antenna masts	q	q	14-7
Whip antennas	"	"	"
Wire Entanglements			
Yields $<$ 1 kt	Δp	Δp	14-6
Yields $>$ 1 kt	q	q	14-7
Small Arms	Δp_{eq}	q_{eq}	14-5
Water Storage Equipment			
Lyster bag, 36 gal	Δp	Δp	14-6
Tank, cylindrical, open top	"	"	"
	Shielded Equipment		
1/4-ton Trucks	Δp	Δp	14-6
Crawler Tractors	"	"	"
Road Graders	"	"	"
Lightweight Radios	"	"	"

Tables 14-5 through 14-7
Pages 14-23 through 14-25
Deleted. USADCA (b)(1)

[redacted]

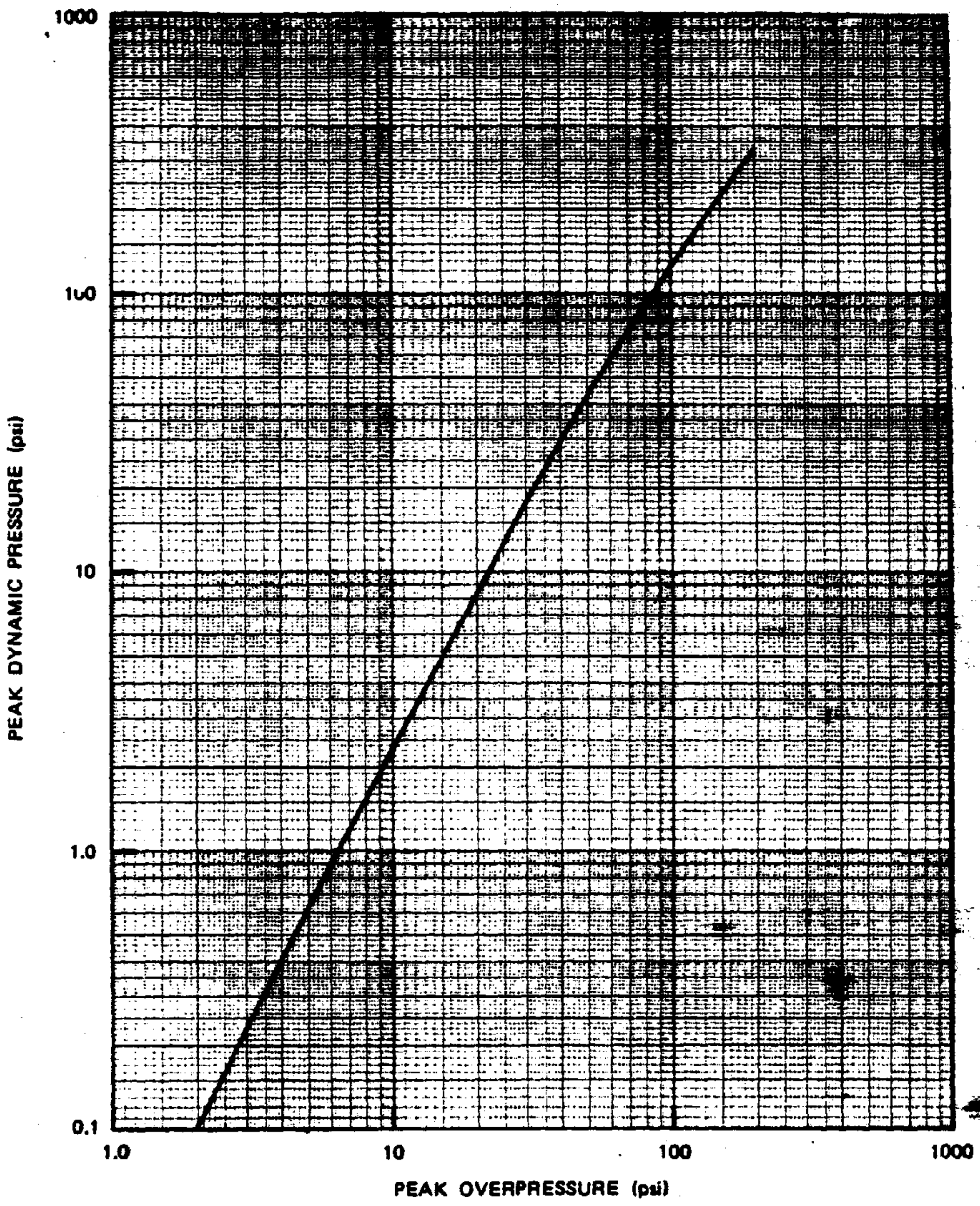


Figure 14–12. [redacted] Peak Dynamic Pressure as a Function of Peak Overpressure [redacted]

[redacted]

Problem 14-1. Calculation of Damage to Wheeled Vehicles

[redacted] Tables 14-5 through 14-7 show values of equivalent overpressure (Δp_{eq}) and dynamic pressure (q_{eq}) necessary to produce a 50 percent probability of at least the damage category indicated to items of equipment listed in Table 14-4. Ground distances must be obtained from Figures 2-18 or 2-19 for Δp_{eq}, and from Figure 2-25 for q_{eq}. In those cases where q_{eq} is lower than shown in Figure 2-25, the corresponding overpressure may be obtained from Figure 14-12. The ground distance corresponding to this overpressure may then be obtained from Figure 2-19 or Figure 2-20.

[redacted] *Scaling.* The height of burst curves of Chapter 2 must be entered with the height of burst or ground distance for a 1 kt explosion. For yields other than 1 kt, the height of burst and ground distance scale as follows:

For equipment listed in Table 14-5,

$$\frac{h}{h_1} = W^{1/3},$$

$$\frac{d}{d_1} = W^{0.4},$$

For equipment listed in Tables 14-6 and 14-7,

$$\frac{h}{h_1} = \frac{d}{d_1} = W^{1/3},$$

where d_1 and h_1 are the distance from ground zero and height of burst, respectively, for 1 kt, and d and h are the corresponding distance and height of burst for a yield of W kt.

[redacted] *Example* [redacted]:

Given: A 10 kt explosion at a height of burst of 200 feet.

Find: The ground distances for each damage category for randomly oriented 2-1/2 ton trucks for both near-ideal and nonideal (light dust) surface conditions.

Solution: From Table 14-4, the equipment is sensitive to total impulse and Table 14-5 is the appropriate table from which to obtain the damage category blast parameters. From Table 14-5, the equivalent overpressures and dynamic pressures for a 1 kt explosion over near-ideal and nonideal surfaces are:

[redacted]

[redacted]

[redacted] *Reliability:* Two factors affect the reliability of damage predictions: the accuracy with which the air blast environment can be predicted; and the accuracy of the damage values or comparable data. The accuracy of the predictions of the overpressure and dynamic pressure environments is discussed in Chapter 2. The values shown in Tables 14-5 through 14-7 are for 50 percent probability with an accuracy of ±25 percent, i.e., the value for a change in damage level is for a 50 percent probability that the greater damage will occur, and the value shown in the table is accurate to within ±25 percent. These reliability and accuracy values are estimates because there are rarely sufficient data to justify a statistical analysis. The damage values with asterisks, signifying limited data, are estimated to be accurate to within ±50 percent. The loss in accuracy resulting from modifications for random orientation and shielding are believed to be small and would have little effect on the overall reliability of the damage prediction.

[redacted] *Related Material:* See paragraphs 14-7 and 14-8, Tables 14-4 through 14-7, and Figure 14-12. See also paragraphs 2-20 through 2-22, Figures 2-18 through 2-20, and Figure 2-25.

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Problem 14-2. Calculation of Damage to Shielded Wheeled Vehicles

[redacted] Tables 14-5 through 14-7 show values of equivalent overpressure (Δp_{eq}) and dynamic pressure (q_{eq}) necessary to produce a 50 percent probability of at least the damage category indicated to items of equipment listed in Table 14-4. Ground distances must be obtained from Figures 2-18 or 2-19 for Δp_{eq}, and from Figure 2-25 for q_{eq}. In those cases where q_{eq} is lower than shown in Figure 2-25, the corresponding overpressure may be obtained from Figure 14-12. The ground distance corresponding to this overpressure may then be obtained from Figure 2-19 or Figure 2-20.

[redacted] *Scaling.* The height of burst curves of Chapter 2 must be entered with the height of burst or ground distance for a 1 kt explosion. For yields other than 1 kt, the height of burst and ground distance scale as follows:

For equipment listed in Table 14-5,

$$\frac{h}{h_1} = W^{1/3},$$

$$\frac{d}{d_1} = W^{0.4},$$

For equipment listed in Tables 14-6 and 14-7,

$$\frac{h}{h_1} = \frac{d}{d_1} = W^{1/3},$$

where d_1 and h_1 are the distance from ground zero and height of burst, respectively, for 1 kt, and d and h are the corresponding distance and height of burst for a yield of W kt.

[redacted] *Example* [redacted]:

Given: A 20 kt explosion at a height of burst of 500 feet.

Find: The ground distances for each damage category for 1/4-ton trucks within revetments, i.e., shielded on two sides.

Solution: From Table 14-4, shielded vehicles are overpressure sensitive and Table 14-6 is the appropriate table from which to obtain the damage category blast parameters. Since no particular orientation was specified, random orientation is assumed. From Table 14-6, overpressures for a 1 kt burst over a near-ideal surface are:

[redacted]

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[redacted]

[redacted]

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[redacted] *Reliability:* Two factors affect the reliability of damage predictions: the accuracy with which the air blast environment can be predicted; and the accuracy of the damage values or comparable data. The accuracy of the predictions of the overpressure and dynamic pressure environments is discussed in Chapter 2. The values shown in Table 14-5 through 14-7 are for 50 percent probability with an accuracy of ±25 percent, i.e., the value for a change in damage level is for a 50 percent probability that the greater damage will occur, and the value shown in the table is accurate to within ±25 percent. These reliability and accuracy values are estimates because there are rarely sufficient data to justify a statistical analysis. The damage values with asterisks, signifying limited data, are estimated to be accurate to within ±50 percent. The loss in accuracy resulting from modifications for random orientation and shielding are believed to be small and would have little effect on the overall reliability of the damage prediction.

[redacted] *Related Material:* See paragraphs 14-7 and 14-8, Tables 14-4 through 14-7, and Figure 14-12. See also paragraphs 2-20 through 2-22, Figures 2-18 through 2-20, and Figure 2-25.

[redacted]

Problem 14-3. Calculation of Damage to Wire Entanglement

[redacted] Tables 14-5 through 14-7 show values of equivalent overpressure (Δp_{eq}) and dynamic pressure (q_{eq}) necessary to produce a 50 percent probability of at least the damage category indicated to items of equipment listed in Table 14-4. Ground distances must be obtained from Figures 2-18 or 2-19 for Δp_{eq}, and from Figure 2-25 for q_{eq}. In those cases where q_{eq} is lower than shown in Figure 2-25, the corresponding overpressure may be obtained from Figure 14-12. The ground distance corresponding to this overpressure may then be obtained from Figure 2-19 or Figure 2-20.

[redacted] *Scaling.* The height of burst curves of Chapter 2 must be entered with the height of burst or ground distance for a 1 kt explosion. For yields other than 1 kt, the height of burst and ground distance scale as follows:

For equipment listed in Table 14-5,

$$\frac{h}{h_1} = W^{1/3},$$

$$\frac{d}{d_1} = W^{0.4},$$

For equipment listed in Tables 14-6 and 14-7,

$$\frac{h}{h_1} = \frac{d}{d_1} = W^{1/3},$$

where d_1 and h_1 are the distance from ground zero and height of burst, respectively, for 1 kt, and d and h are the corresponding distance and height of burst for a yield of W kt.

[redacted] *Example* [redacted]

Given: A 15 kt explosion at a height of burst of 400 feet.

Find: The damage-distance relations for a concertina wire entanglement.

Solution: Table 14-4 indicates that wire entanglements are sensitive to dynamic pressure for yields greater than 1 kt, and that Table 14-7 is the appropriate table from which to obtain the damage category blast parameters. [redacted] The equivalent height of burst for a 1 kt explosion is

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$$h_1 = \frac{h}{W^{1/3}} = \frac{400}{(15)^{1/3}} = 162 \text{ ft.}$$

[redacted]

(b)(1)

[redacted]

[redacted] *Reliability:* Two factors affect the reliability of damage predictions: the accuracy with which the air blast environment can be predicted; and the accuracy of the damage values or comparable data. The accuracy of the predic-

[redacted]

tions of the overpressure and dynamic pressure environments is discussed in Chapter 2. The values shown in Tables 14-5 through 14-7 are for 50 percent probability with an accuracy of ±25 percent, i.e., the value for a change in damage level is for a 50 percent probability that the greater damage will occur, and the value shown in the table is accurate to within ±25 percent. These reliability and accuracy values are estimates because there are rarely sufficient data to justify a statistical analysis. The damage values with asterisks, signifying limited data, are estimated to be accurate to within ±50 percent. The loss in accuracy resulting from modifications for random orientation and shielding are believed to be small and would have little effect on the overall reliability of the damage prediction.

[redacted] *Related Material:* See paragraphs 14-7 and 14-8, Tables 14-4 through 14-7, and Figure 14-12. See also paragraphs 2-20 through 2-22, Figures 2-18 through 2-20, and Figure 2-25.

Problem 14-4. Calculation of Damage to Artillery

[redacted] Figures 14-13 through 14-27 show families of curves that define the damage categories as functions of height of burst and ground distance from a 1 kt explosion for the several classes of equipment listed in paragraph 14-8. Separate curves are shown for near-ideal and nonideal surface conditions.

[redacted] *Scaling.* For yields other than 1 kt the height of burst and ground distance scale as follows:

For Figures 14-13 through 14-21,

$$\frac{h}{h_1} = W^{1/3},$$

$$\frac{d}{d_1} = W^{0.4},$$

For Figures 14-22 through 14-25, and 14-27,

$$\frac{h}{h_1} = \frac{d}{d_1} = W^{1/3},$$

For Figure 14-26,

$$\frac{h}{h_1} = W^{1/3},$$

$\dfrac{d}{d_1} = W^{0.4}$, *except Radomes,* for

which distance scales as,

$$\frac{d}{d_1} = W^{1/3},$$

where h_1 and d_1 are the height of burst and ground distance for 1 kt, and h and d are the corresponding height and distance for a yield of W kt. For convenience, the proper scaling is indicated on each figure.

[redacted] *Example* [redacted]:

Given: A 250 kt explosion at a height of burst of 1,250 feet.

Find: The distance to which severe damage occurs to artillery located on a nonideal surface.

Solution: The corresponding height of burst for 1 kt is

$$h_1 = \frac{h}{W^{1/3}} = \frac{1{,}250}{(250)^{1/3}} = 198 \text{ ft.}$$

The listing given in paragraph 14-8 shows that Figure 14-14 is the appropriate figure to determine damage relationships for artillery. [redacted]

[redacted]

[redacted]

[redacted] *Reliability:* The ground distances for the various damage categories shown in Figures 14-13 through 14-18 and 14-22 through 14-27 are estimated to be accurate generally within ±25 percent, although wide variations might occur for individual items within a class (see paragraph 14-3). These reliability values are estimates because there are rarely sufficient data to justify a statistical analysis. The ground distances obtained from Figure 14-19 through 14-21 are estimated to be accurate within ±50

[redacted]

percent because of the even more limited data and because of the difficulty in aggregating all supply dumps into one class. As described in paragraph 14-8, curves that reflect the yield dependence of the scaling might be expected to provide somewhat more reliable predictions; however, such curves are not available at present.

[redacted] *Related Material:* See paragraphs 14-3, 14-7, and 14-8. See also paragraphs 2-20 through 2-22.

Problem 14-5. Calculation of the Advantage in Shielding Engineer Heavy Equipment

[redacted] Figures 14-13 through 14-27 show families of curves that define the damage categories as functions of height of burst and ground distance from a 1 kt explosion for the several classes of equipment listed in paragraph 14-8. Separate curves are shown for near-ideal and nonideal surface conditions.

[redacted] *Scaling*. For yields other than 1 kt the height of burst and ground distance scale as follows:

For Figures 14-13 through 14-21,

$$\frac{h}{h_1} = W^{1/3},$$

$$\frac{d}{d_1} = W^{0.4},$$

For Figures 14-22 through 14-25, and 14-27,

$$\frac{h}{h_1} = \frac{d}{d_1} = W^{1/3},$$

For Figure 14-26,

$$\frac{h}{h_1} = W^{1/3},$$

$$\frac{d}{d_1} = W^{0.4}, \text{ except Radomes, for}$$

which distance scales as,

$$\frac{d}{d_1} = W^{1/3},$$

where h_1 and d_1 are the height of burst and ground distance for 1 kt, and h and d are the corresponding height and distance for a yield of W kt. For convenience, the proper scaling is indicated on each figure.

[redacted] *Example* [redacted]:

Given: A 250 kt explosion at a height of burst of 1,000 feet over a nonideal surface.

Find: The advantage in shielding engineer heavy equipment at a distance of one mile from the expected ground zero.

Solution: The corresponding height of burst for 1 kt is

$$h_1 = \frac{h}{W^{1/3}} = \frac{1{,}000}{(250)^{1/3}} = 159 \text{ ft.}$$

The listing given in paragraph 14-8 shows that Figure 14-15 is the appropriate figure to determine damage relationships for unshielded engineer heavy equipment, and Figure 14-25 is appropriate for shielded engineer heavy equipment. The corresponding ground distance from a 1 kt explosion for use with Figure 14-15 is (see *Scaling* above)

$$d_1 = \frac{d}{W^{0.4}}$$

$$d_1 = \frac{5{,}280}{(250)^{0.4}} = 580 \text{ ft.}$$

The corresponding ground distance from a 1 kt explosion for use with Figure 14-25 is (see *Scaling* above)

$$d_1 = \frac{d}{W^{1/3}}$$

$$d_1 = \frac{5{,}280}{(250)^{1/3}} = 838 \text{ ft.}$$

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[redacted] *Reliability:* The ground distances for the various damage categories shown in Figures 14-13 through 14-18 and 14-22 through 14-27 are estimated to be accurate generally within ±25 percent, although wide variations might occur for individual items within a class (see paragraph 14-3). These reliability values are estimates because there are rarely sufficient data to justify a statistical analysis. The ground distances obtained from Figure 14-19 through 14-21 are estimated to be accurate within ±50 percent because of the even more limited data and because of the difficulty in aggregating all supply dumps into one class. As described in paragraph 14-8, curves that reflect the yield dependence of the scaling might be expected to provide somewhat more reliable predictions; however, such curves are not available at present.

[redacted] *Related Material:* See paragraphs 14-3, 14-7 and 14-8. See also paragraphs 2-20 through 2-22.

Figures 14-13 through 14-27 on Pages 14-37 through 14-51 are deleted.
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14-9 Untested Equipment [redacted]

[redacted] Although a wide variety of equipment is included in Tables 14-5 through 14-7, many items are not listed, principally because they were never subjected to the air blast environment of nuclear or large HE tests. In some cases it is possible to deduce an approximate set of damage criteria, either because the untested equipment is comparable in some degree to some item that was tested, or because subsystems of the new equipment are similar to subsystems on tested equipment. The principles and the damage agents described in paragraphs 14-1 through 14-6 should aid in predicting damage to untested equipment, although familiarity with subsystem response (a subject beyond the scope of this chapter) would be more satisfactory.*

[redacted] Table 14-8 lists a number of items of equipment for which approximate levels of damage were deduced from the principles outlined previously. The response information shown in Table 14-8 is generally considered to be accurate to within ±50 percent, unless otherwise stated. This is caused by the inherent inaccuracies associated with the use of the comparability principle, which is primarily useful for obtaining estimates. The remainder of this section describes how the damage levels were determined.

[redacted] *Bridges, Mobile Assault:* A specific example of this equipment is the "Bridge, Floating: Mobile Assault, 36-ft." This item should be examined for its response when on the road, and when in the water. Unfortunately no information about its response in the water exists.

[redacted] When on the road and side-on, the critical angle† for overturning is about 45 degrees, which is comparable with a 2-1/2-ton truck. The area of the side-on vehicle is at least twice that of a 2-1/2-ton truck, and the weight is about four times as much. Because the moment of inertia about an overturning axis would be large, the primary response mode is expected to be sliding. However, because of the box-like configuration and the large, flat-topped surface, a large lifting force is quite possible. In addition, the large weight force on each of four wheels is likely to cause a buildup of resistive force during sliding. It therefore appears reasonable to assume that overturning occurs shortly after sliding begins.

[redacted] In the end-on configuration, the sloping surface of the vehicle will cause a significant vertical force. However, the extremely large moment of inertia in this orientation should provide resistance to overturning. The construction of the item, in addition to the flotation gear, may make it vulnerable to low overpressures. A rupture of the hull or flotation gear would make the item useless until repairs are made. In this instance, whether the item was made of steel or aluminum, the thickness of hull, and whether of riveted or welded construction, would be significant. Thermal effects on flotation gear are not expected to cause rupture or burning except at high yields, although the flotation gear may be torn loose in the end-on configuration.

[redacted] Additional information concerning this item would increase the reliability of damage predictions. Until such time as more information becomes available, the following values are recommended.

[redacted]

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* [redacted] P. J. Morris, *Study of Military Field Equipment Response to [redacted]ir Blast and Prediction of Damage (U)* describes predictions based on subsystem response (see bibliography).

† [redacted] Angle through which the item must rotate for the center of mass to be placed over the center of rotation.

‡ [redacted] Use $W^{0.4}$ scaling for ground range.

Table 14-8 page 14-53 is deleted. USANCA (b)(1)

[redacted] *Camouflage Nets.* These items are rarely considered in damage predictions. They are included in Table 14-8 primarily as a possible source of fires. Very low dynamic pressures, on the order of 2 psi, are sufficient to destroy their effectiveness for concealment. Cloth netting generally is destroyed by a thermal exposure of 15 cal/cm^2. Cloth nets can be a considerable fire hazard if this amount of thermal energy is received prior to the arrival of a low overpressure blast of about 5 psi, which may be insufficient to extinguish pre-blast flames. Plastic netting is not as susceptible to burning, but it will melt and char at a thermal exposure of approximately 10 cal/cm^2.

[redacted] *Carriers, Full Tracked.* Some data are available on equipment that predates present equipment, e.g., the Armored Infantry Vehicle, M59. So few data are available on similar current equipment, however, that any attempt to apply M59 information to current equipment could be misleading. Present vehicles are significantly different from the M59 since they are constructed of aluminum, whereas the M59 was constructed of steel. The response of carriers is believed to be similar to that of wheeled vehicles in that a boxlike construction and large areas make it susceptible to overturning. It appears that the damage values for 1/4-ton trucks may be appropriate until actual response information becomes available.

[redacted] *Engineer Construction Equipment.* Tabulated values for road grader and tracked tractors are probably appropriate for the present equipment; however, these response tables are based on very few data points, which undoubtedly affects their reliability. The characteristics of the equipment exposed in nuclear tests are not known, and comparisons with present items cannot be made. It is believed, however, that differences will be relatively small.

[redacted] No test information is available for wheeled scoop loader type equipment. Since it is a four-wheeled, rubber-tired vehicle, comparison with other wheeled vehicles is inevitable. [redacted]

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[redacted] *Howitzers, Self-Propelled.* The M108 105-mm, M109 155-mm, and M110 8-in. self-propelled howitzers are examples of this equipment type. The M108 and M109 howitzers are more similar in mass distribution and geometry to tanks than to the howitzers exposed during nuclear tests. Their somewhat higher profile and more "bulky" construction of the turret indicate they would be more susceptible to overturning than tanks. Nevertheless, the damage values for tanks should provide a good estimate until a closer examination of these items is made. The 8-in. howitzer on the other hand has a configuration similar to howitzers that were exposed at tests; thus, the damage values for the T97 self-propelled howitzer should provide a good estimate.

[redacted] Damage values for self-propelled howitzers are based on very little data, and care should be exercised in using the tank damage values for the M108 and M109. One major consideration not previously mentioned with regard to these items is the lack of data or analysis for howitzers exposed with their gun tubes in a firing position. Such a configuration could change the response of these items materially as a result of a change in the dispositions of blast forces and resisting moments.

[redacted] *Howitzer, Towed.* Three examples of this category of equipment are the M101A1 105-mm light howitzer, M114A1 155-mm medium howitzer, and M115 8-in. heavy howitzer. Damage values are available for the 57-mm antitank gun and the U.K. 25 pounder. The damage values for the 57-mm AT gun probably can be used for the M101A1 105-mm light how-

[redacted] itzer, but insufficient information is available for the M114A1 155-mm medium howitzer, and M115 8-in. heavy howitzer.

[redacted] *Radar Sets.* The AN/MPQ-4A radar set is used primarily to locate hostile mortars and to adjust low-velocity artillery fire. When this equipment is in transit, the antenna group and power supply are each mounted on two-wheeled trailers. The antenna trailer has outriggers for stability. The control unit for the radar and power supply can be removed for remote operation from the power supply trailer, which contains a gasoline generator. When in remote operation the control unit is mounted on a tripod-type stand and weighs about 575 pounds. The only response tables which deal with items that resemble any of this equipment are the ones for skid- and trailer-mounted generating sets. The vulnerability of the power supply trailer might be correlated with a trailer-mounted generator, and the antenna group with a skid-mounted generator. The antenna group is difficult to analyze because of its uniqueness, plus the fact that the trailer outriggers should significantly reduce its vulnerability to overturning. The antenna reflector should be the most vulnerable subsystem of this group, and damage to it would probably determine the overall damage category of the radar system. Thus the damage values for generators may be used as an estimate if the antenna reflector is added as another subsystem, which results in the following approximate damage values for both near-ideal and nonideal blast conditions.

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[redacted]

[redacted] Another radar set that may be used as an example is the AN/TPS-25. This is a combat surveillance, night vision, target acquisition radar. There are three major groupings of components in the system. The antenna, antenna mast, radar modulator, and receiver-transmitter are grouped together and connected by cable to the shelter that contains the radar controls and plot board, and houses operating personnel. The system is powered by a remotely located gasoline generator. The shelter may be located either on the ground or on its transporting vehicle, a 2-1/2-ton cargo truck or 3/4-ton or 1-1/2-ton two-wheeled trailer. All components are packed in the shelter during transit or when not in use. The antenna mast comes in three 6-1/2 foot tubular sections, one, two, or three of which may be used. The antenna mounted on the mast weighs about 150 pounds. The modulator rests on the ground next to the antenna mast. [redacted]

[redacted] *Radio Sets and Terminal Telegraph.* The radio sets AN/GRC-26D, AN/GRC-50, AN/MRC-80, and terminal telegraph-telephone

*[redacted] Use $W^{0.4}$ scaling for ground range.

[redacted]

[redacted] AN/MCC-6 are normally located in electrical shelters mounted on a 2-1/2-ton cargo truck. These shelters have sheet metal walls, metal frames, and wooden interior walls, ceiling and floor. [redacted]

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[redacted] The last example of radio sets is the AN/VRC-12. This is the basic means of communication for vehicles and crew-served weapons upon or within which it is mounted. Its power comes from the vehicle or weapon electrical system. These radios use a whip antenna; they are transistorized except for two tubes in the transmitter driver and power-output stages. The VRC-12 is constructed with printed circuit boards. Therefore, vulnerability should differ considerably from the damage values given for lightweight radios in Table 14-5. Printed circuit boards generally are more vulnerable to shock and vibration than wired circuits. Since these radios are located on or in vehicles and crew-served weapons, the response of the carrier controls the response of the radios to some degree. [redacted] For low yields and shielded vehicles, the following values apply for damage to radios from overpressure.

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[redacted]

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[redacted] *Wheeled Vehicles.* An example of how untested wheeled vehicles might be analyzed is given by this analysis of the M51A2 5-ton dump truck. Few data exist for a 5-ton dump truck (no vehicles exposed at nuclear tests were loaded). The response of a loaded vehicle could be significantly different because the overturning forces would have to be increased. In fact, the possibility of a sliding response would have to be closely examined. The gross unloaded weight of this vehicle is quite large, about 23,000 lb with a center of gravity that is undoubtedly below the center of pressure, so the vehicle probably would overturn were it not for the high overturning moment and angle required. It is not possible to state categorically how this vehicle will respond. Test data do indicate that when it does overturn, the dump body is separated from the chassis, resulting in serious damage. Therefore, the application of the Table 14-5 damage values for 2-1/2-ton trucks will quite likely result in an overestimation of the low-damage-category ground ranges and an underestimation of the high-damage-category ground ranges.

[redacted] A truck-mounted water purification set is an example of a special-purpose wheeled vehicle. This item is quite likely to have different responses, depending on whether the water purification set is in operation or the equipment is closed down for transport. In operation, side

*[redacted] Use $W^{1/3}$ scaling for ground range.

[redacted]

[redacted] panels of the truck body are opened, exposing the purification equipment directly to blast. In addition, the open compartment would increase the clearing times for the reflected pressure and increase the drag coefficient for dynamic pressure. The weight of this item is not known, but it is obvious that the center of gravity would be relatively high. Coupled with the high surface areas, this virtually assures overturning at relatively low blast values. The response of the purification equipment mounted on the truck chassis cannot be estimated without detailed analysis. However, the response of the item as a whole is believed to be quite similar to a 1/4-ton truck.

[redacted] *Supply Dumps.* Damage to supply dumps should be considered in a functional sense. The purpose of a supply dump is to serve as a collection, storage, and dispensing point for materiel. Available information indicates the effect of a blast wave is to scatter containers, at times rupturing the containers and spilling the contents. If the contents are not in bulk form, such as fuel, the contents generally are not damaged. Thus the collection and storage of materiel is not significantly affected. However, the scattering of supplies and blocking of access aisles can degrade the effectiveness of the dump in issuing supplies. The size of the stacks of supplies appears to influence the amount of scattering through some type of volume-vs-area ratio. The blast winds remove boxes, etc., from outer layers in an unravelling process. Since, for a given volume, the area exposed to blast winds depends upon the number of stacks, shielding of supply dumps, such as placing them below ground level, is quite effective in that dynamic pressures have much less area to act on. Overpressure then becomes the dominant factor causing damage. Since contents of supply dumps generally are resistant to crushing forces, an overpressure level of 30 psi is recommended for shielded supply dumps. A dynamic pressure of 5 psi is recommended for unshielded supply dumps. These values are expected to cause major disruption of the supply dump either through damage to or loss of contents or scattering and mixing of containers.

SECTION III

[redacted] DAMAGE FROM CAUSES OTHER THAN BLAST AND NUCLEAR RADIATION [redacted]

14-10 Fire Damage [redacted]

[redacted] Damage to equipment by fire is referred to in some damage reports. Although some 20 occurrences have been noted, they involved only a very small percentage of the equipment exposed. Most fires appeared to be secondary in nature, that is, they were not started by direct thermal radiation ignition. Two equipment items were burned during nuclear tests under exposure conditions in which they could have received virtually no thermal radiation. In addition, a 1/4-ton truck exposed at a 100-ton high explosive test (in which thermal radiation was negligible) also burned.

[redacted] The damage to a 6-kVA generator exposed on a U.K. test is particularly interesting. In the damage report the notation is made, "Fire may have started from fuel from broken carburetor spilling on hot muffler." U.K. practice at nuclear tests was to expose running equipment, that is, the engines were running at the time of the explosion. The six recorded occurrences of fires on U.K. tests represents a considerably larger percentage (about 10 percent) of all U.K. equipment exposed than does the number of fires recorded on U.S. tests. Since this may be due to the U.K. practice of running engines during a test, the incidence of secondary fires in an operational situation may be higher than the U.S. test data indicate.

[redacted] Although it is believed that most fires in the U.S. tests were from secondary rather than

[redacted]

primary thermal ignitions, the source of some of these secondary ignitions is not clear. The two 1/4-ton trucks that burned on one U.S. test were believed to have been ignited by burning asphalt. In one case of a tank exposed to a very low yield burst, personnel reentered the area of the burst shortly after detonation, approaching within 2,000 ft of ground zero at $H + 1$ hour. No smoke or open flames were observed. However, approximately 1/2 hour later some smoke was observed, although its cause is not known.

[redacted] Shielding from direct thermal radiation occurs when the target is below a line from the burst point to the top of any obstacle, that is when the target is in the shadow cast by the obstacle. The obstacle blocks essentially all thermal radiation. Some thermal radiation will still reach the target via the scattering of radiation by the atmosphere. This scattered radiation can be substantial for large yields because the long distances traveled by the radiation increase the opportunities for scattering. Considerable radiation can also be backscattered from clouds. There is not, however, enough information on scattering to be able to predict damage resulting from thermal radiation to shielded targets.

[redacted] Because the incidence of fires was so low in the U.S. tests (though limited British experience suggests that fires could more frequently occur in operational situations), fire damage is not normally considered in assessing damage to military equipment.

14-11 Obscuration of Optical Devices [redacted]

[redacted] Obscuration of optical devices can be an important type of damage. Evidently, the thermal radiation impinging on coated or painted surfaces near an optical surface, together with blast winds, results in the deposit of sufficient sooty material that the optical surface would have to be cleaned prior to use. Most of the information on this phenomenon was obtained from U.S. and U.K. damage reports on exposed tanks, and some scattered data are available on the artillery optics. Although there is no physical damage to the optics, the obscuration is sufficient to preclude their use, and some remedial action must be taken to make them useful. [redacted]

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[redacted] Little is discernible in the data about the effect that orientation has on which surfaces become sooted, but it seems wise to develop criteria for sooting of all surfaces. Since most nuclear tests were conducted under nearly ideal atmospheric conditions, and there probably was little scattering of thermal radiation, sooting was probably limited to those surfaces more directly facing GZ. [redacted]

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[redacted] The data from the exposure of tanks at nuclear tests are sufficiently extensive that obscuration of optics is included in damage estimates for tanks; however, there is insufficient information to apply this process to other optical systems with any reliability.

14-12 Damage by Missiles [redacted]

[redacted] Missiles are objects that are picked up and translated by the blast wave with sufficient velocity that, upon impact with an item of equipment, the stem may be damaged. Examples of such objects are rocks, gravel, sticks, structural debris, battlefield debris, etc. Instances of missile damage are scattered throughout the damage reports of nuclear tests. Some examples are the puncturing of a tire, fuel tank, or radiator by a stick or stone.

[redacted] Missile damage usually has not been included in damage analysis and prediction tech-

[redacted] niques because its frequency of occurrence is quite low, and it is rarely possible to predict when an item of equipment would be damaged by a missile. Missile damage, therefore, generally is not considered in damage analysis. (An exception for sand and gravel missiles is the chipping and cracking of glass surfaces by blast-wind-transported material. This phenomenon is mentioned in damage reports with sufficient regularity to include it as a damage mechanism even though it rarely makes optical systems completely inoperable.)

[redacted] Another possible agent of damage that falls under the general category of missile damage is the deposit of dirt, sand, and gravel in gun tubes and in some cases machine-gun barrels. Although there are several specific references to this problem in the test reports, there are no references for dynamic pressures above 10 psi. The more spectacular physical damage that occurred at high dynamic pressures may have caused this effect to be neglected in the examination of the equipment. There are rare references to sand and dirt getting into the breech mechanism, making it difficult to operate.

[redacted] Deposition of foreign matter in gun tubes does not seem to depend upon orientation of the tubes, which may be explained by the fact that material is transported by both the positive and negative phase of dynamic pressure. In actual combat, there might not be as much sand and gravel as on the desert where nuclear tests were conducted, but there could be other sources of particulate matter available. A little dirt in a gun tube may only mean an increased rate of wear if the gun is fired before cleaning, but it could also lead to more catastrophic damage. Consequently, the possible effects of material deposition within gun tubes should be considered in assessing damage to equipment with such tubes.

14-13 The Effects of Time [redacted]

[redacted] Time itself is not a damage mechanism. However, the time lag between occurrence of damage and efforts to repair the damage may alter the damage level of one or more subsystems of military equipment significantly. For example, hydrostatic lock may develop in overturned engines; fuel, water, and oil may leak, and require replacement before the equipment is functional; the corrosive action of spilled battery acid or solvents can render subsystems inoperable; soft systems, such as electronics, may be exposed to weather, making them inoperable. Such events can not only increase damage levels but also can increase the amount and nature of effort necessary to repair the damage.

[redacted] The damage reported on nuclear tests frequently included some effects of time, although damage reports attempted to compensate for time delays. Test areas often were not reentered nor damage assessments made until many days after the explosion. In an operational situation, particularly if personnel are in a warned protected status at detonation time, recovery efforts would probably start in a matter of hours rather than days. Since the significance of time after damage is extremely difficult to assess quantitatively (because of unknowns in the disposition and capability of repair or recovery efforts soon after detonation) damage assessments included herein do not include the effects of time before repairs can be made.

SECTION IV

[redacted] TREE DAMAGE CRITERIA [redacted]

[redacted] The phenomena associated with transient radiation effects on electronics (TREE) are discussed in Chapter 6. Section VII of Chapter 9 discusses component part and circuit response to nuclear radiation. This section provides estimates of nuclear radiation levels sufficient to cause moderate to severe effects in military equipment. The discussion in this section is limited to electronics, without regard to the system structure or the operator.

[redacted]

[redacted] SYSTEMS ANALYSIS [redacted]

14-14 Types of Systems Analysis Used in TREE [redacted]

[redacted] Two approaches may be used in systems analysis with respect to TREE, and each leads to a different result. The first approach to survivability analysis addresses the question of whether the system will malfunction during or after exposure to a specifically defined threat or a given set of radiation hardness criteria. The end result is that a system can be classified as vulnerable, questionable, or hard to that specified radiation threat. The survivability of the system can then be improved by redesign of the more vulnerable circuits or subsystems. Although the system may be classified as hard to the specified radiation threat, there is no certainty that the vulnerability levels of the system will have been identified. This approach to survivability analysis may be adequate in some instances, but changes in threat environment, system mission or tactics will require another complete analysis.

[redacted] The second approach to survivability analysis differs from the analysis described above in two major respects. First, it includes a detailed vulnerability assessment which defines the susceptibility level of each circuit or subsystem to all types of radiation threats, not just a particular one. Second, it is concerned with the statistics of failure for any component or subsystem variations in failure level for all radiation threats. With these data, the system may be evaluated for a specifically defined threat and any variations in the threat resulting from changes in system employment or tactics. In this section interest centers on the expanded survivability analysis approach.

14-15 The Complexity of Performing System Analysis for TREE [redacted]

[redacted] The complexity of circuit and system analysis is increased when it becomes necessary to understand the system response during and after exposure to nuclear radiation. This environmental constraint can change or modify the characteristics of the electronics in a very time dependent manner. The level of understanding and the accuracy in prediction of individual component part response often is not sufficient to allow accurate analysis. Therefore testing (in many cases extensive testing) is necessary to establish component part response and to verify circuit analysis. This, however, is not the complete answer to the additional complexity. The radiation response of component parts can vary widely. For example, samples of a certain transistor type can sustain significant variations in percentage of gain degradation for a given neutron exposure. Component part response can also depend on the particular bias conditions under which the part is being operated. That is, the component part could be most vulnerable to a particular radiation component (e.g., gamma rays) in one bias condition while in another bias condition it may be most vulnerable to a different radiation component (e.g., neutrons). The degree of susceptibility can change with bias conditions. As stated in Section VII of Chapter 9, the response of component parts can depend on prompt dose or dose rate. In survivability analysis, both cases must be considered. This possibility of double dependence also applies at the circuit and subsystem levels of response.

[redacted] The circuit and subsystem design also are critical with respect to radiation susceptibility. The fact that a component has a significant response to a certain level of radiation does not mean that the circuit that uses that component will be susceptible to the same level of radiation. The radiation susceptibility level of the circuit could be higher or lower than the levels of any of the component parts used in the circuit. The tolerances within which each component part and circuit has to perform in order for the system to achieve its function is a factor

[redacted]

[redacted] in establishing the susceptibility of the circuit. Information of this nature, however, usually is only available during the design phase and frequently must be obtained through a detailed circuit analysis. The tolerances of the critical component parts and circuits, once obtained, are typically so narrow that another complete analysis of the component response and circuit interactions is required to establish the survivability of the system.

[redacted] For similar reasons a problem occurs in the analysis of generic functions, such as an amplifier, flip-flop, or clock circuit. Circuit functions can be performed by a large number of circuit configurations using a very large variety of component part types. Thus, it would be necessary to review all pertinent configurations and component part types that would accomplish the desired function in order to determine the survivability of the generic function. Also, the level of confidence associated with a specific vulnerability level for a generic function would be much lower than that for a specific circuit with specific component parts.

[redacted] The last factor that affects the accuracy of the system analysis is the determination of the environment. That is, the environment that is used to generate the TREE response data (for use in the analysis) has to be correlated to the actual use environment. This correlation may be in error by as much as an order of magnitude unless care is taken to include all factors that may affect the correlation.

[redacted] All these influences are in addition to the normal circuit and systems analysis problems. The resultant analysis becomes a complex manipulation of many interactions. Hence this type of analysis requires skill and understanding in order to approach a reasonably good characterization of the system response to a nuclear-weapon threat.

14-16 Characteristics of the Analysis Used in This Section [redacted]

[redacted] A primary concern of this section is to provide an appreciation for the survivability levels of military electronic equipment exposed to radiation from nuclear weapons. For the purposes of this section, only two levels of survival are used – a "sure safe" level and a "sure kill" level. The term "sure safe" implies a zero percent probability of failure while the "sure kill" implies a 100 percent probability of failure. A great deal of generalizing has taken place in this section (i.e., the discussion is by generic term, and each generic term, such as radio, has hundreds of variations). As a result very low confidence levels are necessarily placed on the "sure safe" and "sure kill" terms. Even with a particular system it is difficult to establish a particular probability of failure with a high degree of confidence because of the problems involved in evaluation of circuit and system responses.

[redacted] These levels of "sure safe" and "sure kill" were established without regard as to whether the system was operating or not operating at the time of the explosion. The levels were established on the basis of system analyses that have been performed on systems in each of the categories. Where analysis information was lacking, estimates were made on the basis of the component parts typically used in that particular generic class and worst-case circuit conditions were assumed. No consideration was given to the aging of the equipment.

[redacted] Utilization of the estimates presented in the latter portion of this section requires that the system be considered to be divided into subsystems according to function. The relative vulnerability of each subsystem can then be estimated on the basis of the subsystem levels presented in the text of this section. If by chance a subsystem does not fit the generic functions listed, the best estimate would have to be based on

[redacted]

[redacted] the susceptibility of the component parts used in that system. Component part susceptibility is reviewed in the following subsection and is discussed in more detail in Section VII of Chapter 9.

[redacted] THE SURVIVABILITY LEVELS PROVIDED IN LATER PARTS OF THIS SECTION ARE MEANT TO BE USED ONLY AS GUIDES. THEY *SHOULD NOT* BE USED TO FULFILL A REQUIREMENT OR TO ESTABLISH THE VULNERABILITY OR SURVIVABILITY OF A PARTICULAR SYSTEM. More detailed information may be obtained from the TREE (Transient-Radiation Effects on Electronics) Handbook (see bibliography) as well as other references listed in the bibliography.

[redacted] REVIEW OF ELECTRONIC SUSCEPTIBILITY TO NUCLEAR RADIATION [redacted]

14-17 Component Part Vulnerability [redacted]

[redacted] Any discussion of vulnerability or survivability is ultimately based on some definition of failure. In keeping with the scope of this manual, two cases of failure are considered. First, any condition which renders the electronic equipment inoperable following exposure to a nuclear burst constitutes a system failure. The second definition of failure involves those cases where it is critical that the equipment function during the radiation exposure in order to complete a critical mission. In the latter case, a system malfunction initiated during the exposure that causes loss of the mission objective is classified as a failure.

[redacted] Under the first definition of failure, consideration is given primarily to permanent damage in the electronics. The loss of one or more bits of information within a computer as a result of transient effects would not constitute a failure by this definition, if, after reinitialization, the computer functioned satisfactorily, and if the system operation was not critical during the time of the weapon burst.

[redacted] Permanent damage to electronics can result from (see Section VII, Chapter 9):

[redacted]

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[redacted] Collectively speaking, burnout problems from voltage and current transients normally are not a problem with [redacted] infrequent exceptions may occur by gate breakdown in MOS transistors, or in poorly designed circuitry. Since gamma rays are not attenuated appreciably in their passage through the electronics package, [redacted] The internal and external X-ray environments can differ considerably, depending on packaging, and other shielding, and the X-ray spectrum (hot or cold, see Chapter 4). [redacted] This assumes roughly 98 percent attenuation of X-rays in transit through packaging, which implies a relatively cold source or effective shielding.

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[redacted] Neutrons normally affect semiconductor component parts long before they affect other component parts such as capacitors, resistors, and transformers. Among the semiconductor types, unijunction transistors, silicon-controlled

[redacted]

[redacted]

[redacted]

[redacted] rectifiers, low-frequency and power-type transistors are notably poor performers. The maximum tolerable neutron fluence (or range of fluences) for various semiconductor types are listed below.

[redacted]

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[redacted] Thus, in analyzing systems for hardness, the subsystems containing sensitive semiconductors are likely to be the most vulnerable.

[redacted] The third type of permanent damage, likely to occur during a nuclear burst is X-ray induced thermomechanical shock. Thermomechanical-shock effects are such that, for a specific device type, there is no unique radiation level that will cause a specific effect. [redacted]

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These levels are the values *at* the component part. Because of the variation in X-ray spectra for various conditions, it is not possible to suggest general X-ray levels external to the systems that will result in these effects.

[redacted]

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[redacted] The second type of failures (failures during exposure) typically are caused by the ionization (gamma and X-ray) dose rate. In component parts, the typical effect is the introduction of potentially large photocurrents that result in a temporary malfunction of the component. This effect could result in a system malfunction if, for example, the extraneous current pulse fired a pyrotechnic device prematurely, or changed a bit of data in a logic circuit required for critical guidance functions. Devices particularly susceptible to large photocurrents are large-area, and/or high-gain devices. Typically the photocurrents generated below 10^6 rads (Si)/s are not sufficient to cause malfunction. Failures resulting from prompt dose effects are closely associated with the dose rate effects. Prompt dose is that dose accumulated during the initial gamma pulse (~0.1 microseconds, see Chapter 5) whereas the total dose is that accumulated over seconds or up to a minute (or longer, if the equipment is in a residual radiation field). Prompt doses as low as 0.1 rad (Si) can

*[redacted] To a first approximation, n/cm^2 ($E > 10$ keV, fission) $\simeq$ n/cm^2 (1 MeV silicon damage equivalent).

†[redacted] Some quartz resonator crystals and MOS field-effect transistors are very sensitive to gamma radiation.

[redacted]

[redacted] cause silicon control rectifiers to malfunction, and, normally, prompt doses over 100 rads (Si) will perturb most component parts sufficiently to cause all unhardened circuits to malfunction.

14-18 Subsystem Vulnerability [redacted]

[redacted] Generally it is those subsystems that use the more vulnerable semiconductor component parts that will limit the hardness of a system to radiation. The relative sensitivity of semiconductor devices to radiation was outlined in paragraph 14-3. Some of the more common circuits that are likely to use these component parts, and the attendant approximate hardness levels will now be described.*

[redacted] Unijunction transistors commonly are employed in time-delay circuits, pulse generators, clocks, pulse-shaping circuits, and as a trigger device driving SCR's. [redacted]

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[redacted] Power transistors generally are of two types: low-frequency types, such as those used in power supply dc-dc convertors or series regulators; and radio frequency (rf) power-amplifier types. [redacted]

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[redacted] Linear integrated circuits (amplifiers, etc.) are more susceptible to permanent damage than digital types, but the former are not used widely in military equipment. [redacted]

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[redacted] Possibly the most critical part of a system is its power source. Power supplied from a motor-generator, dynamotor or battery is least likely to fail in a radiation environment. [redacted] Failure levels are typical of those listed for power transistors.

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[redacted] Circuits that must retain information are susceptible to transient damage. That is, transient photocurrents can introduce erroneous information into the memory system or even change the information in the memory system.

[redacted] Integrated circuits can be triggered into a malfunction called "latchup" by the prompt ionizing dose at levels from 10 to 100 rads (Si). Latchup can be important because this particular condition may burn out the circuit or just simply not allow recovery to proper operation for periods long compared to the normal circuit-recovery times.

[redacted] Section VII, Chapter 9 provides more detailed information concerning circuit response to radiation.

[redacted] TREE-DAMAGE ESTIMATES [redacted]

[redacted] Estimates of system damage from nuclear-burst radiation are based on two factors. First is the likelihood that a given system type contains a susceptible circuit or subsystem as described in paragraph 14-18. Second is the probable environment in which the equipment will be used. Differences in shielding afforded by aircraft, missile, ship, or jeep installations could be significant for some components of nuclear burst radiations.

[redacted] The estimates that are given in succeeding paragraphs are not all inclusive in the types

*[redacted] Estimates are based on the assumption that the equipment was not designed with radiation hardness as a parameter, i.e., they are unhardened.

[redacted]

[redacted]

of systems or installations covered. The cross section of systems should provide some basis for estimating the radiation damage threshold of other similar equipment.

[redacted] Radiation levels given in the following paragraphs are considered to be external ambient levels. The gamma environment assumes monoenergetic photons having an energy of approximately 1 to 1.5 MeV. A slightly degraded fission spectrum is assumed for neutrons. The X-ray sources postulated for these estimates are blackbody spectra [redacted]

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14-19 Ground Equipment [redacted]

[redacted] Estimates of radiation levels sufficient to cause failures as previously discussed are shown in Table 14-9 for typical ground installations or ground support equipment under the heading "sure kill." A lower threshold for failure, below which the equipment in question may be considered operable is referred to as "sure safe." All radiation levels are external ambient values that have meaning only for *unhardened* systems. For hardened systems, the hardening specifications should be consulted. It should be borne in mind that the fact that a system has been hardened does *not* mean that it will survive all radiation environments. It should, however, survive at least those to which it was hardened. It is further assumed that for most reasonable surface encounters [redacted]

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[redacted] No ambient exposures are given for X-rays (cal/cm^2), since these depend strongly on the X-ray spectrum, which in turn, is extremely dependent on the weapon type and the degradation of the spectrum through the intervening space. [redacted] Except under unusual circumstances, X-rays probably do not pose a significant threat for ground equipment.

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14-20 An Example of Ground Equipment Survivability Estimation [redacted]

[redacted] The Lance support system provides an illustration of the use of Table 14-9. The missile itself is found under the heading "Ground and Sea Support Equipment"; however, the levels listed for the Lance are associated only with the missile and not with the launch support equipment or the communications equipment necessary to direct the launch. The associated critical electronic equipment for launch can be listed as follows:

1. Radio receiver and transmitter, or transceiver
2. Batteries to fire the missile and to operate the launch vehicle
3. Fire control system for the missile.

[redacted] The survivability levels for most of these subsystems can also be found in Table 14-9 and are listed on page 14-67. The firing system, not being listed in the table, must be estimated. A basic description of this system implies that it is a box of electrical toggle switches and lights, which apply power and indicate operation. These component parts are not particularly susceptible to radiation. Therefore, they should be at least as hard as the systems with semiconductor devices. Therefore, they will be considered as part of the communication electronics without affecting the analysis.

[redacted] With this summarized information any of three possible situations can be visualized for analysis:

[redacted]

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[redacted] The critical factors affecting mission completion in the first case are:

Page 14-66 with Table 14-9 Deleted. USANCA (b)(1)

[redacted] [redacted]

[redacted]

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[redacted]

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[redacted] For this case the gamma rate would not be critical, since the missile is not in operation and the other equipment does not have to function during the burst. [redacted]

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Either the neutrons or gamma rays specified for the sure-kill level could cause significant problems, and both should be considered.

[redacted] The second case. [redacted]

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[redacted] The sure-safe and sure-kill levels for this situation appear to be the same as the previous case. However, the gamma dose rate could cause problems and should be considered in the sure-safe level.

[redacted] For the third case the missile is dependent solely on itself for control and the levels of survivability are the same as those shown for the missile alone.

14-21 Aircraft Systems [redacted]

[redacted] Estimates of sure safe and sure kill radiation levels in aircraft systems are shown in Table 14-10. These levels are considered to represent external ambient conditions. As was the case for ground equipment, the total dose is not considered to be a problem, and thermomechanical shock from X-rays is not considered important. However, the ionization rate includes both the X-ray and gamma-ray rates.

[redacted] The functional breakdown for aircraft systems is more complex than that for ground systems, since many mission functions require several generic functions within the subsystems. As an example, penetration aids, such as terrain clearance radars, include power sources, radars, computers, flight control links and crew station data display consoles. A brief listing of subsystems that are considered to be part of a mission function are shown in the table. Depending on the type and mission of the aircraft of interest, some of these functions may not be critical or may not even be present in the system. For specific equipment it may be necessary to refer to the levels presented in the previous Table 14-9.

14-22 An Example of Aircraft Survivability Estimation [redacted]

[redacted] To clarify the process of analysis, two cases are considered. The first case is a single-engine spotter plane and the second is a jet fighter similar to the F-111A.

[redacted] Considering first, the spotter aircraft, the generic functions are:

Pages 14-68 and 14-69 with Table 14-10 deleted. USANCA (b)(1)

[redacted]

[redacted]

[redacted]

1. Flight control
2. Crew station
3. Propulsion system
4. Mission and traffic control.

Of these, one function that might be critical to the mission is the Mission and Traffic Control. The crew may not be able to communicate their observations at a critical time, even though they may be able to escape if other generic functions failed. [redacted] If all functions except the crew station were considered, the survivability levels would still be the same. [redacted] Considering the modern fighter aircraft, it would appear that all generic functions listed in Table 14-10 might be associated with the aircraft. Depending on the mission of the plane, various combinations of these generic functions might be critical. For example, if the fighter was used for battlefield support, penetration aids would not be critical. The worst-case survivability levels would occur if both penetration aids and either the air-to-air or air-to-surface missiles were critical for mission completion. [redacted]

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14-23 Missile Systems [redacted]

[redacted] The missile systems included in Table 14-11 are categorized according to mission and guidance type. Thus, the damage criteria, in general, are not representative of a specific system, but reflect the mean susceptibility of systems within each category. Furthermore, unless otherwise specified, all systems are assumed to be unhardened. The categories are not all-encompassing. Where no information was available, estimates were made as noted. Sure-safe and sure-kill levels are given in terms of radiation levels external to the system. Although not a great problem for ground or aircraft systems, X-rays represent a much more formidable threat to missile systems operating at altitudes above 20 kilometers, hence, this information is included. The sources of X-rays postulated for these estimates are blackbody spectra [redacted] No problems are anticipated with the total gamma dose effects unless the dose exceeds 10^5 rads (Si). The prompt dose effects are taken into consideration in the dose rate terms. The dose rate estimates include both the X-ray and gamma ray rates. The dose-rate estimates are based on the damage caused by ionization effects, whereas the column head the "X-ray Exposure" includes estimates based on the damage caused by the thermomechanical effects. No example is provided since it is only necessary to select the correct classification for the missile to establish its survivability levels. There are basically three phases critical to the flight of missiles:

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1. Storage
2. Powered flight
3. Reentry.

A prime factor that would influence the survivability of a missile in storage is not necessarily the electronics vulnerability associated with the missile but, rather, the shielding effectiveness provided by the storage area (e.g., missile silo). The activation and ground-control electronics would be evaluated by using Table 14-9. The powered flight would be concerned with both the missile and the reentry vehicle. And, last, the reentry would be concerned only with the reentry vehicles.

Page 14-71 with Table 14-11 deleted, USANCA (b)(1)

[redacted] [redacted]

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